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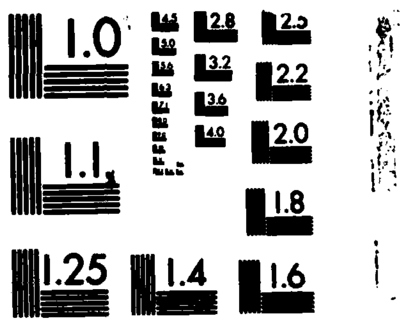

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Currently, topographic products such as contour, slope, and aspect are commonly derived from computer processing of digital grid-point elevation models (DEM). DEM's can be labriously created by a user from an analytical plotter equipped with profiling capability. Alternatively, a user can acquire a DEM produced by an externa source, but then be constrained by the production resolution or accuracy which might not be suitable for the user's application.

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In this study, previously digitized 3-dimensional terain data are combined and converted to a 3 arc second (user-defined) cell matrix. Multiple elevation data points falling into the same cell were averaged to provide a single elevation value and those cells without an elevational value were flagged. The existing elevation data could then be displayed via stereo super-position over a photographic model established on an analytical plotter and those flagged cells could be profiled. This paper presents the method involved in building a DEM from 3-dimensional cartographic data and weighs the benefits and shortfalls of this method.

DEM SYNTHESIS FROM THREE-DIMENSIONAL CARTOGRAPHIC DATA

Roberta Carroll
Daniel Edwards
Center for Artificial Intelligence
U.S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060

BIOGRAPHICAL SKETCH

Roberta Carroll received her B.S. degree in Mathematics from Indiana University of Pennsylvania in 1976 and her M.S. degree in Geodetic Science from Ohio State University in 1979. Currently, she is a cartographer with the Research Institute of the U.S. Army Engineer Topographic Laboratories (USAETL) performing research in computer-assisted photo interpretation.

Daniel Edwards is a 1981 honor graduate of Ohio State University with B.S./M.S. degrees in Natural Resources. He has served as a consultant to the Ohio Department of Natural Resources regarding delineation of Ohio surface mines using Landsat MSS data. Currently, he is a physical scientist with the Research Institute of the USAETL involved in computer-assisted photo interpretation research.

ABSTRACT

Currently, topographic products such as contour, slope, and aspect are commonly derived from computer processing of digital grid-point elevation models (DEM). DEM's can be laboriously created by a user from an analytical plotter equipped with profiling capability. Alternatively, a user can acquire a DEM produced by an external source, but then be constrained by the production resolution or accuracy which might not be suitable for the user's application.

Recently, the integration of stereoplotters with geographic information systems has resulted in limited terrain data production in X,Y,Z coordinates (3-dimensional digital cartographic data). In those cases where detailed 3-dimensional data exists, building a DEM from this database can save labor and preserve user-defined resolution and accuracy criteria.

In this study, previously digitized 3-dimensional terrain data are combined and converted to a 3 arc second (user-defined) cell matrix. Multiple elevation data points falling into the same cell were averaged to provide a single elevation value and those cells without an elevational value were flagged. The existing elevation data could then be displayed via stereo superposition over a photographic model established on an analytical plotter and those flagged cells could be profiled. This paper presents the method involved in building a DEM from 3-dimensional cartographic data and weighs the benefits and shortfalls of this method.

INTRODUCTION

To date, spatial data capture and representation of a 3-dimensional physical world is accomplished primarily through a 2-dimensional (X and Y) data capture process. Elevation, (Z), has largely been treated as a separate entity unrelated to physical features on the topography. Recent attempts to compensate for this deficiency have focused on the merging of planimetric data with digital grid point elevation data. The merging of Landsat data with Defense Mapping Agency (DMA) digital terrain elevation data (DTED) (Tanaka, 1979) or DMA digital feature analysis data (DFAD) with DTED (Federhen, 1984) illustrates recognition of this problem.

DEMs provide a relatively compact and efficient machine-processable format for representing physical topography. Contours, slope, and aspect are commonly derived from computer processing of DEMs. A user requiring digital terrain elevation data must either acquire a DEM produced by an external source or create this product. Frequently, a DEM is not available from an external source for a given area. Futhermore, if one does exist it may not be at the required resolution or accuracy needed for a specific application. Alternatively, a DEM may be laboriously created from an analytical plotter equipped with a profiling capability. Errors are possible and can be introduced in this process due to the redundancy of the operator's task and to hardware plotter problems encountered during profiling.

Recent merging of stereoplotters with geographic information systems has resulted in limited terrain data productions in X, Y, Z coordinates. This permits direct data entry by an analyst and storage of this data in a computer-processable format. Growth of this technology and production of 3-D digital data will intensify due to market demand from such diverse areas as robotic vehicle navigation, computer image generation, and terrain modeling. In those cases where 3-dimensional data exists, building a DEM from this database can save labor and preserve user-defined resolution or accuracy.

In this study, a detailed 3-D terrain analysis database was used as the basis for the production of a digital grid point elevation database. This paper briefly describes the hardware, software, and methods used to generate this DEM.

HARDWARE and SOFTWARE

Efforts at the USAETL, through a program in computer-assisted photo interpretation reseach (CAPIR), have matched an analytical plotter equipped with stereo superposition graphics with a geographic information system (GIS) to provide the mechanism for 3-dimensional data capture and management. The analytical plotter used during this study is APPS-IV. It is a medium accuracy plotter rated at ten micrometers after correction using an affine transformation (Greves, 1982). Stereo superposition graphic CRT's are mounted in the rear housing of the plotter. The graphic CRTs display digitized spatial data which is introduced through beam splitters directly into

the optical path of the plotter stereoscope. This is viewed by the analyst 3-dimensionally superimposed over the photogrammetric model. These graphics are updated ten times per second so that the displayed data tracks the imagery as the analyst traverses the stereo model. The APPS-IV has been enhanced with a profiling capability which allows collection of digital elevation data along evenly spaced profiles. Editing a portion of the digital elevation matrix can be performed within the profiling system without having to reconstruct the entire DEM.

The geographic information system used for data capture during this effort was the Analytical Mapping System (AMS). It allows one to aero-triangulate, digitize, edit, verify, and then database the results. The digitization is in arc/node format with attribute entry and the data is stored in geographic coordinates.

3-D TERRAIN DATABASE

In this study, 3-dimensional digital cartographic data was taken from a terrain analysis of the Fort Belvoir area conducted in order to test and demonstrate CAPIR capabilities developed at USAETL (Edwards,1983). NASA U-2 color infrared photography (scale 1:130,000) was the primary data source for the terrain analysis. Two stereo pairs were triangulated using field-checked and photo-identified first and second order survey points. Initially, landform, surface drainage, soils, and landcover were individually interpreted and digitized as shown in Figure 1. A transportation classification was later started in conjuction with this study, but currently remains partially completed. The actual terrain category boundaries in each classification were interpreted during on-line stereo digitization. The graphic feedback provided by stereo superposition of the cartographic data permitted visual verification of the geographic accuracy of the data during digitization.

The terrain analysis was limited to an area covered by the U.S. Geological Survey Fort Belvoir 7 1/2 minute quadrangle. A 3 arc second DEM for this area contains 22,500 elevation points. This could be laboriously created using the profiling capability of the analytical plotter. In this investigation, the existing elevation data within the five listed terrain analysis files were combined to form a partial DEM. Profiling could then used to complete the DEM matrix.

DEM SYNTHESIS

The following section details the steps involved in reformatting the cartographic data from a vector format (as produced by AMS) into a raster format, with the grid spacing of the DEM defined by the user. This conversion was accomplished by a combination of Fortran programs and Sort/Merge routines resident on the host computer.

The data exported from AMS is changed from an arc-node format to a polygon format complete with a polygon attribute header

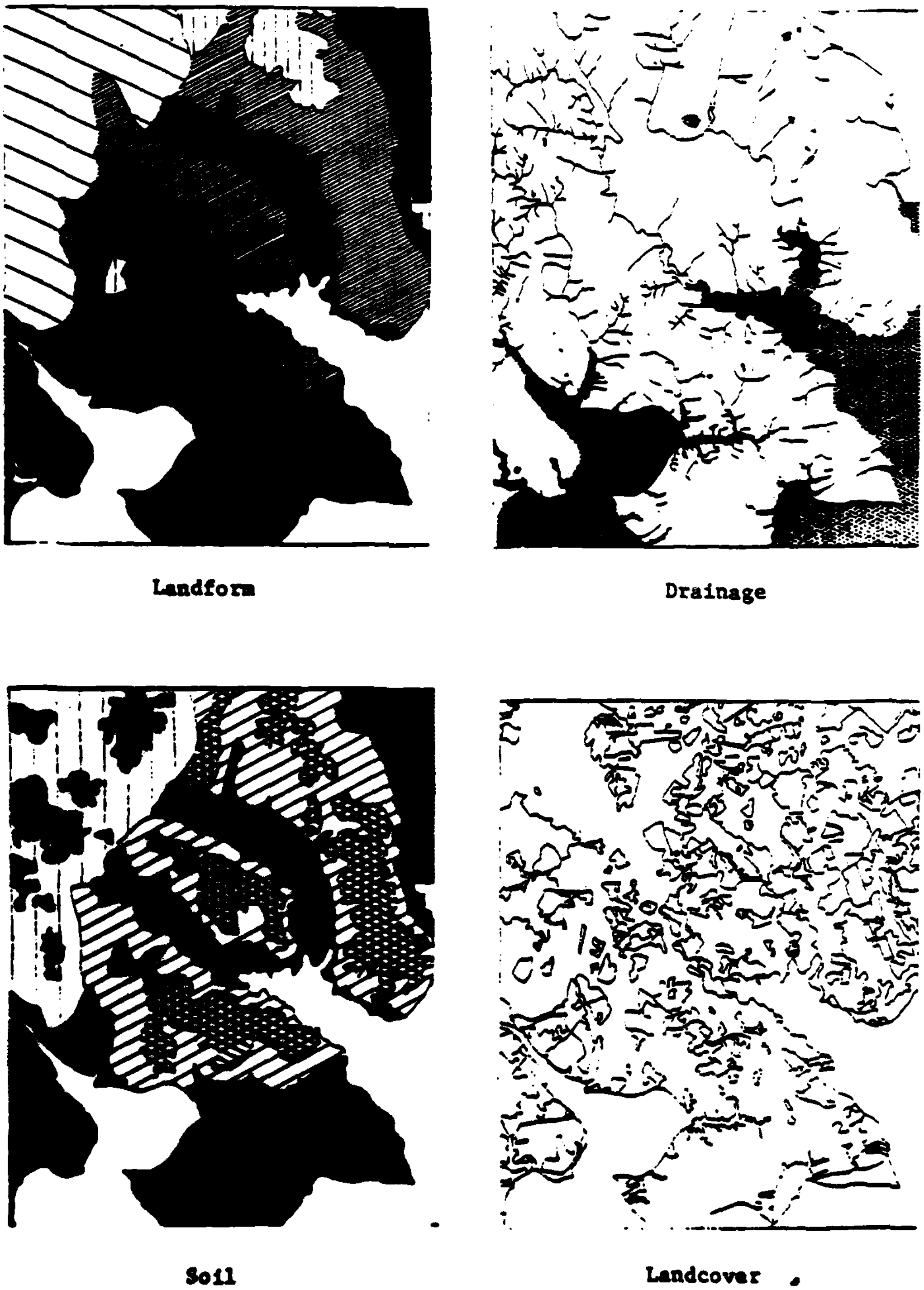

Figure 1

tag. In order to use this data, the header information had to be stripped off the polygon data files leaving only point data. The number of 3-dimensional data points in each of the five terrain analysis files varied widely and are listed below.

Terrain Analysis File	Number of Points
Landform	3715
Drainage	15325
Soil	7543
Landcover	15665
Transportation	7761

In order to simplify the programming, all of the points were merged into one file of 50009 points. The data was then sorted by latitude and the minimum and maximum values stored to provide the northern and southern boundaries of the DEM. Next, the 3-dimensional values were sorted by longitude, placed into 3 arc second divisions, and then resorted by latitude within each of these longitudinal divisions. The longitude values were sorted in descending order because longitudinal values decrease from west to east in the western hemisphere. This sorting provided an ordered grid of X,Y,Z data sorted by latitude and longitude.

After sorting, multiple entries of the same X,Y,Z data points were evident This is a result of the ANS software transforming arc-node data into polygon data. Points which are members of boundary lines between 2 or more polygons are entered for each of the individual polygons. For example,

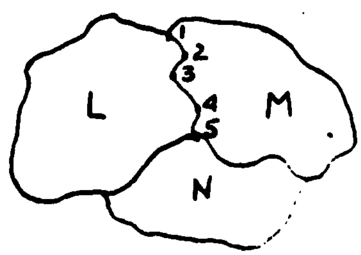

Figure 2.

in Figure 2 the latitude, longitude and elevation for points 1,2,3, and 4 will appear for both polygons L and M. The data for point 5 appears in polygons L, M and N. The redundant data values were deleted for two reasons. First, this reduced the overall amount of data to be handled and thus decreased the computer processing time. Second, in a later program the elevations which are included in each DEM grid cell (3 arc second) are averaged to compute the elevation for that cell. Multiple entries of the same value will bias this result. In the Fort Belvoir test case, the number of data points was reduced from 50009 points to 24157 points. This reduced data was then combined to create a partial DEM.

Within this partial DEM, if a grid cell had 2 or more elevation values, then the cell was assigned the average of these values. If no data was available then that particular cell was tagged with the value 99999. This formed a matrix of values, a partial DEM.

The areas within this DEM containing no elevation value can then be filled in using the profiling capability of the APPS-IV. The partial DEM could be displayed using the graphic superposition CRTs mounted in the rear of the APPS-IV. The cells containing no elevational value (99999) would not be displayed over the photogrammetric model established on the plotter. Then, using the profiling capability of the analytical plotter, the areas without elevation data could be bounded and profiled.

DISCUSSION

This method of creating a DEM from 3-dimensional cartographic data has several advantages. First, it exploits available, existing data. Second, the time and effort required to create a DEM is minimized since only a portion of the matrix must be compiled through profiling. Finally, the accuracy of the DEM may be improved since the averaging of the elevation values within a cell reinforces that final value.

Several limitations are inherent in this method. First, this process requires 3-dimensional cartographic data. Currently, X,Y,Z cartographic data is not commonly available. However, as mentioned earlier, production of this data is expected to become more widespread as additional systems linking an analytical plotter with a GIS become available. Second, the benefits of using this method increase with the density of the cartographic data set. Clearly, the more detail, the less data needs to be gathered through profiling. Sparse data sets accrue negligible benefits from this method. Finally, the averaging of elevation values within a cell has a smoothing effect on the DEM. Thus, extreme values are filtered out in these cases.

A fairly simple method of DEM synthesis has been presented in this paper. In the future, more sophisticated techniques will enhance this procedure. Artificial intelligence rule-based classifiers which would relate elevational values based on select terrain category types such as water, plains, or alluvial fans would further reduce the DEM synthesis effort. Such rule-based classifiers would be handled by an expert system.

In conclusion, a variety of methods and tools will be needed to meet the need for terrain information. In the future, advances will be made in cartographic data capture, management, and exploitation. This technique of using existing 3-dimensional data to create a DEM, has potential to be one of these tools.

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